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Estimation and representation of long-term (>40 year) trends of Northern-Hemisphere-gridded surface temperature: A note of caution

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[1] Several quantitative estimates of surface instrumental temperature trends in the late 20th century are compared by using published results and our independent analyses. These estimates highlight a significant sensitivity to the method of analysis, the treatment of data, and the choice of data presentation (i.e., size of the smoothing filter window). Providing an accurate description of both quantitative uncertainties and sensitivity to the treatment of data is recommended as well as avoiding subjective data-padding procedures. *INDEX TERMS:* 1620 Global Change: Climate dynamics (3309); 3299 Mathematical Geophysics: General or miscellaneous; 1699 Global Change: General or miscellaneous; 6620 Public Issues: Science policy. **Citation:** Soon, W. W.-H., D. R. Legates, and S. L. Baliunas (2004), Estimation and representation of long-term (>40 year) trends of Northern-Hemisphere-gridded surface temperature: A note of caution, *Geophys. Res. Lett.*, *31*, L03209, doi:10.1029/2003GL019141.

1. Introduction

[2] It has been estimated that the Earth's composite air and sea surface temperature increased by approximately 0.6 ± 0.2°C in the 20th century [*IPCC TAR*, 2001, Third Assessment Report's (TAR) chapter 2]. These same analyses also suggest that the surface warming may have accelerated during the last two decades of the 20th century, with a linear 20-year trend of about 0.10 to 0.20 ± 0.07°C per decade, depending on the particular data-set adopted (as summarized in Table 2.1, 2.2 and 2.3 of *IPCC TAR*, 2001). While the error bars represent a plausible assessment of "uncertainties in the annual anomalies due to data gaps, urbanisation over land, and bias correction to SST [sea surface temperature]" [*IPCC TAR*, 2001, 115, which refers to work by *Folland et al.*, 2001], more robust and reliable methods for the quantification of sampling biases, errors and uncertainties for the construction of local, regional and global-scale climatologies are needed [e.g., *Christy et al.*, 2001; *Pielke et al.*, 2002; *Arnfield*, 2003]. Analyses such as *Folland et al.* [2001] that rely on climate model results should be avoided because current climate models are deficient in representing the current climate [e.g., *Lindzen*, 1994; *Johnson*, 1997; *Pielke*, 2001].

[3] We appreciate, and here leave aside, the unresolved questions concerning the many recent efforts to relate the air temperature variabilities recorded by these short-term instrumental records to the broader perspective of historical changes in the climate system over the past millennium or so through natural paleoclimatic indicators [see for example exchanges between *Mann et al.*, 2003 and *Soon et al.*, 2003]. But issues regarding the resolution, detection and quantification of long-term (i.e., multidecadal or centennial) temperature trends, even through the use of instrumental records, are far from settled. Figure 1 illustrates this point with a collection of published figures by (a) *IPCC TAR* [2001], (b) *Mann* [2002], (c) *Mann et al.* [2003] and (d) *Mann and Jones* [2003]. Figure 1 highlights both the remarkably warm level and the rapid rate of warming of the last two decades of the 20th century that have been presented in the smoothed or filtered instrumental record of the Northern Hemisphere. Further, visual inspection shows a sudden acceleration to about 0.25°C per year in the period 2002 through 2003 between the lowest estimate [*Mann*, 2002] and the highest [*Mann and Jones*, 2003].

[4] Does the accelerated warming trend presented in Figure 1d simply depend on the smoothing or filtering process, which relies sensitively on the details of the application?

[5] The objectives of this paper are:

[6] (1) to inter-compare several general methods of representing instantaneous long-term trends estimated from the same temperature record but yielding significantly different values, as assembled in Figure 1. Trends are defined to involve time scales greater than 40 years (to conform to the results in Figure 1) and trends have been estimated from (i) a simple running mean, (ii) a smoothing with the use of a more sophisticated filter such as the Hamming filter as prescribed for the results in IPCC TAR (Figure 1a) and (iii) a frequency-filtering technique, namely, the wavelet transform; and

[7] (2) to ask if one can emulate the instrumental data trends shown in Figure 1, and if so under what assumptions, and if not, why not.

2. Data and Methods

[8] The data used here are the combined terrestrial air and sea surface temperature record for the Northern Hemisphere (downloaded November 4, 2003 from the public access URL of the Climate Research Unit at the University of East Anglia: http://www.cru.uea.ac.uk/cru/data/temperature/.). Only the annual-mean anomaly (relative to the reference period 1961–1990) series from 1856 through 2002 were used for our study concerning estimates of long-term (>40 year) warming or cooling trends. The annual temperature data are accompanied by error bars of two standard deviations (±0.05°C) for the period after 1951 with the formal uncertainties expanded to four times larger during the 1850s.

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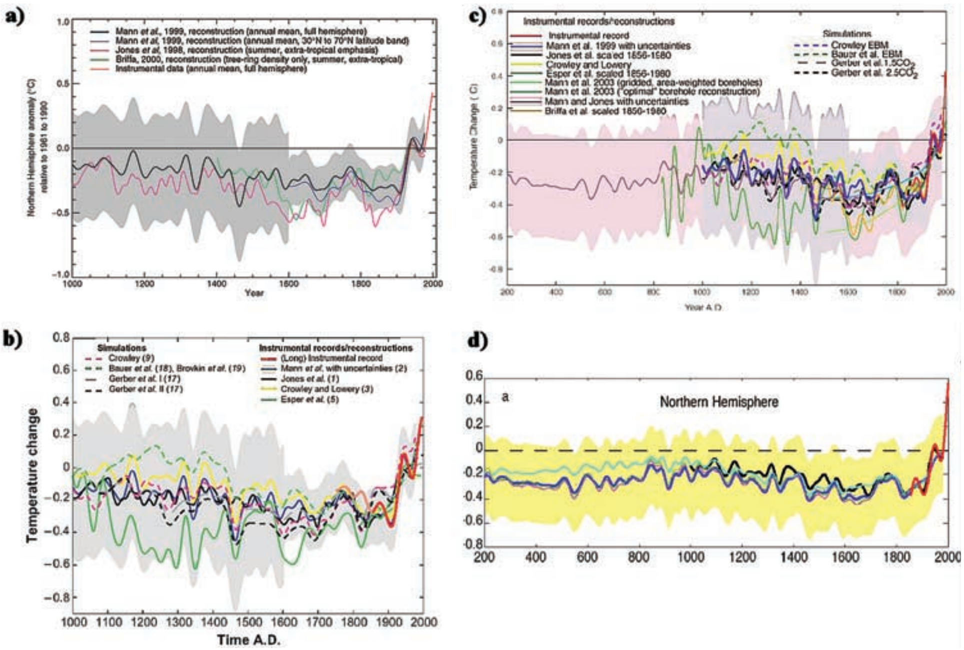

Figure 1. Published Northern Hemispheric surface temperature trends that suggest an unprecedented (relative to the past 1000 to 1800 years) warming of the late 20th century as shown by the smoothed or filtered thermometer records in (a) *IPCC TAR* [2001, Chapter 2, p. 134], (b) *Mann* [2002], (c) *Mann et al.* [2003] and (d) *Mann and Jones* [2003]. Note both the similarity of the smoothed instrumental series in all panels for the mid-to-late 19th century to early 20th century interval but a significant difference in the actual heights of the trend line at 2000, especially between (b) and (d). (Insert (a) is reprinted with permission from the IPCC; Insert (b) is reprinted with permission from *Mann* [2002], Copyright 2002, AAAS (http://www.sciencemag.org); Inserts (c) and (d) are reproduced with permission from American Geophysical Union).

[9] The three methods of trend estimation and representation adopted here are standard approaches [e.g., *Robeson*, 1997], with the exception of the frequency-filtering technique. This last method uses a version of the adaptive wavelet transform algorithm by *Frick et al.* [1998] that has been previously applied to characterize and quantify the variability in Central England air temperature records [*Baliunas et al.*, 1997]. The Hamming-weight filter [$w(i) = 0.54 - 0.46\cos\{2\pi i/(n-1)\}$ where i is the year/data point within the window and n is the length of the window] was selected by the *IPCC TAR* (see their Figure 2.21, p. 134): "All series were smoothed with a 40-year Hamming-weights lowpass filter, with boundary constraints imposed by padding the series with its mean values during the first and last 25 years." We note that alternative filter window widths of 10, 20, 30 or even 5 and 50 years had all been applied by various authors to characterize the long-term Northern Hemisphere temperature trend in recent publications. This introduces subjectivity in the quantification of long-term air temperature trends. We shall adopt a 40-year window width for a more direct comparison with published trends of Figure 1.

[10] In this short paper, we do not discuss the currently unresolved issues concerning the different air temperature trends deduced from surface thermometers and from satellite-based and/or balloon-based measurements, especially over the last 20–25 years. We also do not discuss the physical arguments necessary for justification in considering long-term temperature trends, rather than seasonal and interannual or even decadal-scale changes, for the association with persistent climatic forcings like the enhanced level of atmospheric carbon dioxide.

3. Results and Discussion

[11] Figure 2 shows results from the three different methods of estimating and representing long-term (>40 year) trends in the gridded annual surface temperature of the Northern Hemisphere from 1856–2002. The simple running mean (Figure 2a) and wavelet-transform frequency filtering (Figure 2c) cases were performed with no data padding, while the Hamming-filter weighting (Figure 2b) case prescribed data padding with mean values of the first and last 25 years of the record at left and right end points, respectively (red curve). The last procedure traces the steps taken by IPCC author(s) for producing Figure 2.21 in TAR (p. 134), shown here as Figure 1a.

[12] We successfully replicated the TAR's early 20th century curve presented (Figure 1a,) but not its late 20th century trend, even when the exact time interval specified by the TAR, 1900–1999, was used. The last point of the 20th century is too low in our calculation (0.25°C if endpoints were filled after 1999 [not plotted here] or >0.3°C if endpoints were unjustifiably filled after 2002, shown in Figure 2b) while the *IPCC TAR* Figure 2.21 (Figure 1a here) reaches a significantly higher value, of at least 0.4°C, by 1999. We were able to get the high value of >0.4°C (green curve in Figure 2b) if we padded the forward endpoint with the value of 2002 temperature anomaly (thus we also padded the backward end point with the 1856

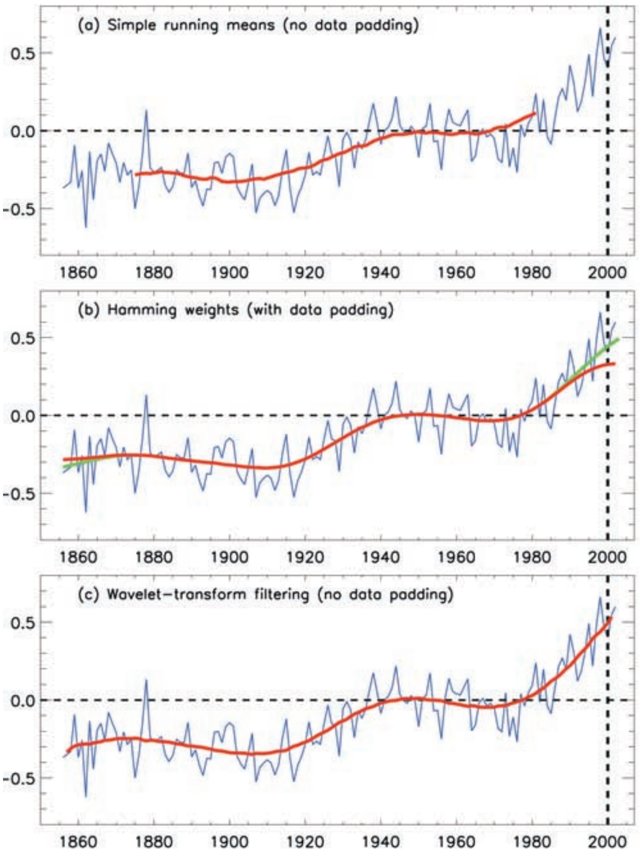

Figure 2. The yearly mean Northern Hemisphere surface temperature anomaly from 1856 through 2002 (blue) superposed with trend estimates (red) using (a) a simple 40-yr running mean with no padding of endpoints; (b) a 40-yr Hamming-weight smoothing with padding of endpoints with mean values of first and last 25 years so that the trend line can be represented at both endpoints of the original series (at 1856 and 2002) as discussed in the caption of Figure 2.21 of IPCC TAR; and (c) a filtered series removing all timescales between 2 and 40 years using the wavelet transform. The additional trend estimate (green curve) in (b) represents the alternative scenario of padding the respective endpoints with values at 1856 and 2002 rather than the 25-year means specified by IPCC TAR. The horizontal zero-line (dashed curve) represents the mean anomaly of the instrumental base period 1961–1990. Note that significant quantitative differences exist in the various representations of the trend curves near the year 2000. This results from different data smoothing methods and data handlings used near the forward endpoint of the curve.

anomaly for 20 years, which makes a slight change in the curve), even though the 2002 data were unavailable when TAR was prepared. But this disagreement with TAR neither implies nor proves that our calculations are wrong. As noted below, we essentially recover, by Hamming-filter weighting, the curves in *Mann* [2002] (as Figure 1b here and red curve in Figure 2b) and *Mann* [2000] (not shown here). The discrepancies seen in Figure 1a and Figure 2b cannot be explained by an argument that the *IPCC TAR* author(s) used a different data set because we can recover almost exactly the near-decadally-smoothed curve in *IPCC TAR*'s Figure 2.7a on p. 114 (not shown here). Perhaps TAR performed other analyses that were not discussed.

[13] The difference in the estimated trend of the late 20th century between Figure 1d and Figure 1b, about 0.25°C per year, is very large and if physically real would have an important implication for global warming discussions. The trend by 2000 of >0.4°C published by *Mann et al.* [2003] (our Figure 1c) is similar to the TAR result (our Figure 1a), but significantly below the >0.5°C value in *Mann and Jones* [2003; our Figure 1d].

[14] We were unable to reproduce the smoothed Northern Hemisphere temperature trend of *Mann and Jones* [2003, their Figure 2a or Figure 1d here], which is puzzling because we did recreate their smoothed Southern Hemisphere temperature trend and its amplitude (their Figure 2b not shown here). We were able to do so by applying the 40-year Hamming-weighted filter to the University of East Anglia's Southern Hemisphere land and sea surface temperature record from 1856–2002, not as specified by TAR, but by padding the respective endpoints backward with the value at 1856 and forward with value at 2002.

[15] Figures 3a, 3b, and 3c show the progression toward increasingly higher values at 2000 over the short 1–2 years spans from the publications of Figure 1b to Figures 1c and 1d. Figure 3d illustrates the same quantities as in Figure 2b and Figure 2c, but now with both axes adjusted to more closely resemble the most recent 200 years of Figure 1d. Our wavelet-transform lowpass filtered curve (red) resembles, though does not exactly correspond to, Figure 1d [*Mann and Jones*, 2003] but there is no indication that Figure 1d was derived from such method of trend estimation. Our 40-year Hamming-weight smoothed curve

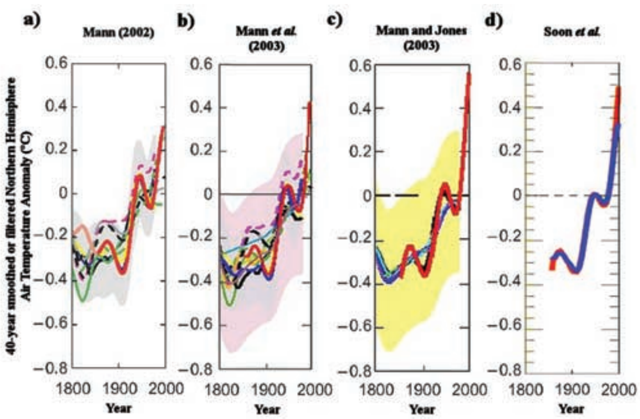

Figure 3. The comparison of the 40-yr low-pass filtered series using wavelet transform (red curve, same as Figure 2c) with the 40-yr Hamming weights smoothed series (blue curve, same as Figure 2b) with endpoints padding recommended by the author(s) of Figure 2.21 of the IPCC TAR. Our curves (panel d) are, in turn, compared on the same time-temperature scales with smoothed series (all the red-solid curves) by (a) *Mann* [2002] (Figure 1b), (b) *Mann et al.* [2003] (Figure 1c), and (c) *Mann and Jones* [2003] (Figure 1d). A progression is seen toward increasingly higher values at 2000 over the short 1–2 years span of publication interval. Figure (3a) is reprinted with permission from *Mann* [2002], Copyright 2002, AAAS (http://www.sciencemag.org).

(with padding of endpoints with respective mean values of first and last 25 years of data record) is similar to Figure 1b [*Mann*, 2002] (and results in *Mann*, 2000) and this is likely the method of smoothing performed in these articles.

[16] Quantification of the late 20th-century Northern Hemisphere temperature trend is highly sensitive to the choice of methodology and treatment of data. Padding additional data at the endpoints (as performed in Figure 2b and TAR) simply to fill in a trend line to cover the full extent of the actual series (say, 1856 through 2002) is unphysical and can be misleading. The data-padding procedure is the logical equivalent of perfect knowledge in retrodicting the past and predicting the future.

[17] The remaining methods (Figure 2a and 2c) give two extreme results. The running mean without data padding (Figure 2a) is agnostic about the present, and argues that the actual trend of the late 20th century (smoothed) variability will be decided by what occurs in the coming decades. The running mean does offer a very consistent framework for the objective standard for trend estimation and representation, even though the most recent data may visually suggest a different trend.

[18] Although the wavelet-transform frequency-filtering method (Figure 2c) is the least sensitive to treatment of endpoints (yet is quite sensitive in some realistic scenarios we examined offline), temporally local information may be overemphasized, hence biasing the long-term trend value. Thus, there is no compelling physical argument to prefer the wavelet representation to the running mean (Figure 2a).

[19] *All* series in Figure 1 have similar, if not exact, instrumental trends and data values during the mid-to-late 19th century to early 20th century, while trend differences in Figure 1 point to significant differences in the imposed endpoint conditions of the late 20th century. We note that too little time has passed between the publication of the several articles to expect significant changes to the input temperature data. A close study of Figure 2b and 2c suggests the difference of trends at the end of the 20th century (i.e., about 0.25°C in Figure 1 [between Figure 1d and Figure 1b] and about 0.2°C in Figure 2 [between red curves in Figure 2b and 2c]) can be explained by the method of trend representation and/or the treatment of data at the forward endpoint (i.e., the updating of record with new data points) before smoothing or filtering rather than any real physical changes. Additional sensitivity tests (not shown here) support this explanation. We find no justification for the apparently spurious, high value of the late 20th-century trend in Figure 1d.

4. Conclusions

[20] We were successful in replicating the instrumental surface temperature trends in several previously published results. However, we failed to reproduce the long-term (>40 years) Northern Hemispheric surface thermometer temperature trends shown in Figure 2.21 of *IPCC TAR* (as Figure 1a here) and in Figure 2a of *Mann and Jones* [2003] (as Figure 1d here). We conclude that published results suggesting that the Northern Hemisphere surface air temperature has increased by the extremely rapid rate of about 1 to 2.5°C per decade during the last one year (2002–2003) (see Figure 3) are most likely artefacts of methodology and procedure of trend smoothing. Accurate communication of methods and avoidance of data-padding procedures for smoothing and/or filtering of climatic time series should be incorporated in reporting data trends.

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